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DRYING AND CURING CHEMICALLY TREATED COTTON BATTING

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DRYING AND CURING CHEMICALLY TREATED COTTON BATTING

by
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INTRODUCTION

An improved cotton batting product being developed through research at the Southern Regional Research Laboratory offers promise for use on automobiles, mattresses, and furniture. The research is sponsored by the Textile Waste Association, The National Cottonseed Products Association, The National Cotton Batting Institute, and the Foundation for Cotton Research and Education, in cooperation with the Southern Utilization Research and Development Division of the United States Department of Agriculture.

The objective of the research is the development of cotton-cushioning products having greater resilience, greater dimensional stability, and greater coherence than the conventional cotton batting. Considerable progress has been made in achieving these properties. Application of thermosetting resins to react or crosslink chemically with the cellulose of the cotton fibers has increased the resilience of the product; and use of film-forming, usually thermoplastic resins or latexes to form interfiber bonds has enhanced both coherence and dimensional stability.

The process developed during this research consists of spraying openly arrayed webs of fibers with a treating formulation, followed by conventional lapping, then drying and curing. Optimum product performance is usually achieved when the treating formulation is 20 percent solids, consisting of 50 percent thermosetting resin and 50 percent thermoplastic film-forming resin or latex (1, 3, 4, 5, 6, 9)[2]. The optimum wet add-on is approximately 100 percent by weight of the "as is" cotton fibers. Table 1 shows some typical treating formulations.

TABLE 1. --Typical formulations for preparing cotton batting (20% total solids in solution)

		Percent
1.	Methylated methylol melamine ---	30
	Urea formaldehyde -----------	30
	Acrylic resin --------------	40
	Oxalic acid ----------------	
	Dicyandiamide -------------	
	Wetting agent -------------	
2.	Methylated methylol melamine ---	60
	Vinyl acrylic copolymer -------	40
	Magnesium chloride ----------	
	Wetting agent -------------	
3.	Urea formaldehyde -----------	40
	Methylated methylol melamine ---	20
	Vinyl acetate copolymer -------	40
	Magnesium chloride ----------	
	Urea -------------------	
	Wetting agent -------------	
4.	Methylated methylol melamine ---	67
	Vinyl acetate copolymer -------	22
	Styrene butadiene copolymer ----	11
	Magnesium chloride ----------	
5.	Urea formaldehyde -----------	30
	Melamine formaldehyde--------	30
	Acrylonitrile latex -----------	40
	Catalyst (proprietary) Urea -----	
	Wetting agent -------------	

During the exploratory phases of this research, samples approximately 1 by 4 ft. by 1.0 in. thick were dried in a steamheated, forced-draft, cabinet-type oven at temperatures between 185 and 200 F., and cured in a gas-fired, forced-draft, cabinet-type oven at temperatures between 300 and 320° F. Since positive through-circulation of air could not be achieved in these cabinet-type ovens, drying generally took about 2 hrs. and curing took an additional 30 min. However, before the process could be made commercially feasible, drying time had to be reduced to 3 to 5 min. and curing to 1 1/2 to 3 min.

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[1] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

[2] Numbers underlined and in parentheses refer to Literature Cited, p. 10.

During the development of the improved cotton batting product, an unusual characteristic was observed. Although most materials shrink during drying, cotton batting increases in volume. This characteristic made it necessary to restrain samples of batting to control both the density and the thickness of the product.

Considerable data on the theory, design, and performance-cost of drying are available in the literature (2, 7, 8, 10). However, except for preliminary process evaluation, such data cannot be applied cirectly to drying conditions for a new product. Final design of a dryer should always be based on experimental tests in dryers that simulate as closely as possible the proposed commercial scale.

Part I of this paper describes preliminary determination of conditions for drying and curing of cotton batting spray-treated with a resin and latex formulation. Part II reports the design, construction, and operation of the pilot-plant continuous oven used for drying and curing.

I. PRELIMINARY DETERMINATIONS OF CONDITIONS FOR DRYING AND CURING

Of the methods considered for drying spray-damp cotton batting, through-circulation of hot air seemed most promising. A requisite for use of this method was the determination of the air permeability of in-process cotton batting. An S. W. Frazier cloth permeability tester[3] was modified by installing over the sample opening a pyrex cylinder 3 in. in diameter by 1 in. in height to accommodate samples of cotton batting. Method 5450, Section IV, Part 5, of the Federal Standard Stock Catalog, was used to determine that at a pressure drop of 0.5 in. of water, 100 c.f.m. of air could be passed through 1 sq. ft. of spray-damp batting having a density of approximately 2.0 lb./cu.ft. and a thickness of 1 in.

Experimental Simulation of Full-Scale Oven

Based upon these findings, a jig that would accommodate a 10 in. by 10 in. sample of cotton batting was constructed. Figure 1 shows the salient features of the jig.

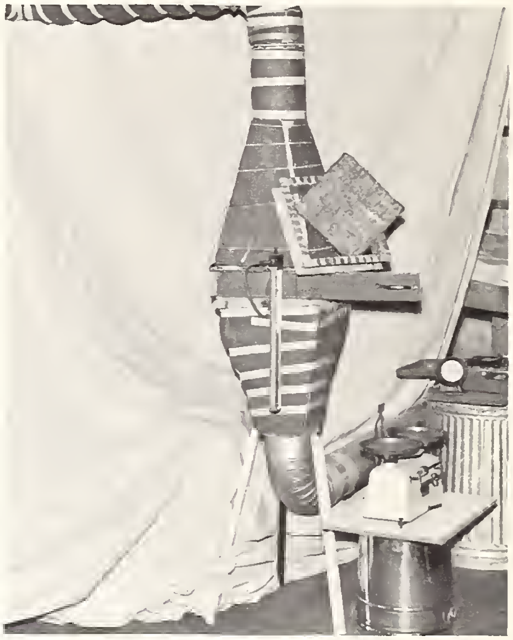

Figure 1.--Test jig used for drying tests.

It was hypothesized that with proper control of the air velocity and suitable pressure drop through the material, air pressure rather than mechanical means could be used to control the expansion of the sample during drying. Test of this hypothesis demonstrated that at sample densities up to 2.5 lb./cu.ft., air could be used to control density in experimental equipment.

Conditions and Procedures

To obtain data on the drying characteristics of cotton batting, the following conditions were selected to achieve a 1 in. thick product whose density was about 1.8 to 2.2 lb./cu. ft.

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[3] Trade names are used in this publication solely to provide specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture, or an endorsement by the Department over other products not mentioned.

1. The feed to the garnett would consist of 60 percent first-cut linters and 40 percent textile wastes of various grades, including picker, fly, motes, and in some cases sweeps.

2. The treating solution would contain the necessary catalyst and buffer, and 20 percent solids made up of 60 percent methylated methylol melamine and 40 percent acetate copolymer.

3. The drying temperature would be held to 200 F. maximum to avoid resin migration.

4. Drying time would be 2 to 3 min.

5. The curing temperature would be 300 ± 10°F.

6. Curing time would be about 1 min.

The following procedure was used in these tests.

Sample Preparation

Blended cotton fibers consisting of 60 percent linters, and 40 percent textile wastes in the form of a picker lap were fed to a sample garnett at a rate of 80-85 g./min. to produce a continuous web 12 in. wide. The web was sprayed with the treating solution to a calculated 100 percent wet add-on while in transit from the garnett to a 24 in. diameter takeup reel used to simulate a lapper. Experimental batts consisting of 20 webs were built up. Samples 10 in. by 10 in. were cut from the resulting 1 ft. by 7 ft. spray-wet batts and placed in polyethylene bags for use in the drying tests. As each sample was removed from the bag, the sample was measured for thickness and was weighed. After adjustment of air temperatures, a preliminary setting of differential pressure across the sample was made, using a previously dried and cured 10 in. by 10 in. sample of batting. This expedited adjustment of differential pressure when the spray-damp sample was placed in the jig.

Drying Studies

In the drying tests, the samples were removed from the jig at 30 sec. intervals, weighed, and measured for thickness, then returned to the jig. The drying times reported do not include the time required to make these measurements. Drying was continued until two successive weighings showed no change. Near the end of each 30 sec. interval, the air temperature and airflow were measured.

Variables Investigated

Drying Time

Data on drying time are shown in table 2. In these tests values of drying time, drying air temperature, and differential pressure were selected, and measurements were made on: (1) airflow rate through the sample, and (2) increase in thickness of sample. Although samples could be dried in as little as 60 sec., they failed to expand sufficiently. The high flow rates needed to accomplish drying and the concomitant pressure drop through the samples compressed the batting during what appeared to be a critical phase of the drying process. There are instances where values of airflow rate and differential pressure appear to be inconsistent, perhaps because of variations in porosity due to nonuniformity in sample construction or to poor fit in 10 in. by 10 in. sample holder. For these reasons, differential pressure across the sample was used as a basis for adjusting the airflow through the sample.

When samples were dried for 2 to 3 min., the rate of airflow, velocity, and corresponding pressure drop through the samples could be decreased. These samples demonstrated an increase in thickness comparable with that observed in experimental samples dried in cabinet-type drying ovens.

Samples dried at 190° F. in the desired 2 min. interval at differential pressure of 0.45 in. of water exhibited satisfactory expansion and density. The airflow rate under these conditions was approximately 80-90 c.f.m./sq.ft. through 1 in. thick samples.

In general, if the drying time was 1 min. or less, the expansion was insufficient and resiliency was poor. When drying time was excessive, 4 min. or more, the resin and latex had a tendency to migrate, as indicated by toughness at the outer surfaces of the batting.

TABLE 2.--Conditions evaluated for drying chemically-treated cotton batting in an experimental jig

(Variations in airflow rate and thickness corresponding to selected values of drying time, temperature, and differential pressure)

Drying time	Temperature	Pressure differential	Average air flow rate	Increase in thickness
Minutes	Degrees F.	Inches of water	Cu. ft/min.	Percent
1.0	215	3.20	430	7.4
1.0	230	1.70	380	12.5
1.0	205	0.90	150	16.3
1.5	205	0.70	240	25.0
1.5	180	0.90	185	23.0
2.0	190	0.45	80	30.0
2.0	190	0.45	90	26.0
3.0	287	0.30	98	33.3
3.0	175	0.45	95	30.0
3.0	185	0.35	70	35.0
3.0	276	0.15	47	30.0
3.0	190	0.20	40	25.0

Edge Sealing

In commercial production, it would be impractical to expect perfect edge-sealing. To ascertain the effect of imperfect edge-sealing (and consequent short circuiting of air around instead of through the samples) on the drying rate and expansion of the product, samples cut to 8 in. by 10 in. were tested. The results of these experiments are given in table 3.

These 8 in. by 10 in. samples could also be dried in 2 min. at a differential pressure of 0.5 in. of water, and their expansion was satisfactory. Under these conditions, however, airflow had to be about 500 c.f.m./sq. ft. of batting 1 in. thick, over five times the airflow required with a good edge-seal.

As can be noted from tables 2 and 3, the expansion could not be related directly to any other variable; however, there was a signifi-

TABLE 3.--Effect of imperfect edge seal

(Samples 8 in. X 10 in. dried in a holder 10 in. by 10 in.)

Drying time	Temperature	Pressure differential	Average airflow	Increase in thickness
Minutes	Degrees F.	Inch of water	Cu. ft./min.	Percent
2.0	210	0.50	525	26.0
1.5	215	0.20	400	17.5
5.5	220	0.15	225	37.0
7.0	220	0.15	180	34.0

cant increase in thickness when conditions for drying required about 2 min. For all practical purposes then, use of this time cycle with pressure differentials approximating 0.3 to 0.5 in. of water could be considered optimum. Greater differentials compressed the samples unduly, whereas the lesser pressure differentials significantly increased the time to dry. It is postulated that there is a critical time during drying when excessive compression by air adversely affects the ability of the sample to expand.

Curing Time

Because of limitations of the equipment, temperatures of the air could not be adjusted from the drying temperature of 200°F. to the curing temperature of 300° F. in less than 5 min.; therefore, four 10 in. by 10 in. samples were dried at 200° F., the jig temperature adjusted to 300° F., and the samples then cured for 1 1/2 min. This sequence allowed the samples 1/2 min. to heat up and 1 min. to cure. The data in table 4 was obtained with this time allowance for the sample to warm up from 200° F. to 300° F., and a minimum of 1 min. at 300° F. to assure curing of the resin. Table 4 also shows that the curing did not affect the thickness of the sample at pressure differentials up to 1.35 in. of water and airflow rates up to 255 c.f.m./sq.ft. of sample. From these data, it appears that, if warranted, high pressure differentials can be used during the curing process without increasing the density of the product.

Temperature of the Batting and Surrounding Air

Also investigated were changes in temperature of the upper and lower surfaces of the sample and changes in wet and dry bulb temperatures of incoming and exit drying air. Thermocouples from a multipoint strip chart recorder were embedded in the upper and lower surfaces of the treated batting, and wet and dry bulb thermocouples were located about 6 in. above and below the sample. When the treated sample was placed in the experimental dryer, all dry bulb thermocouples registered the same temperature as the incoming drying air. Figure 2 shows the relative locations of wet and dry thermocouples and temperatures recorded during drying.

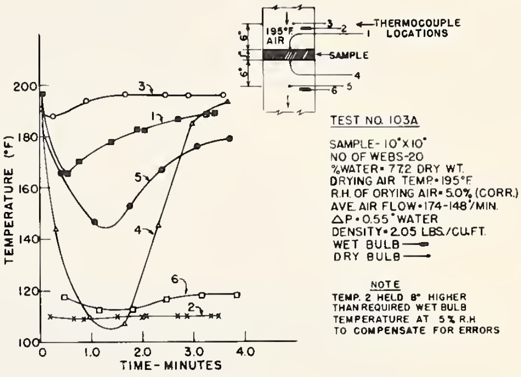

Figure 2.--Temperatures of batting and of surrounding air during experimental drying test.

Temperatures of the incoming and exit air recorded by the wet bulb thermocouples were

TABLE 4.--Effect of high curing airflow rates on thickness of samples

(Samples dried 2 minutes at 200° F. followed by 0.5 minute to heat up to 300° F., and then 1 minute to cure at 300° F. Samples 10 in. by 10 in.)

Drying			Curing		
Pressure differential	Average airflow	Increase in thickness	Pressure differential	Average airflow	Change in thickness
Inch of water	Cu. ft./min.	Percent	Inches of water	Cu. ft./min.	Percent
0.70	142	28.5	1.70	352	1.0
0.75	137	25.0	1.85	352	0.5
0.75	133	21.4	1.25	255	0.0
0.75	123	26.8	1.35	255	0.0

inaccurate because the true wet bulb adiabatic saturation temperature requires an air velocity of at least 600 ft./min. Readings were approximately 8° F. higher than the temperature required for the 5 percent relative humidity selected for this test. This increase in wet bulb temperatures is partly due to radiation effects from the chamber walls, heat loss through insulation, location and design of wet bulbs, and low air velocity in the chamber. For this reason, relative humidity values were not plotted in figure 2.

Temperature records 1 and 4 of figure 2 clearly demonstrate the heat-insulating properties of cotton and the need for drying in a layer of optimum economic thickness.

Dry bulb temperature record (designated 5 in figure 2) was used to estimate a value for the average temperature of the exit air. This estimate was used in calculations of heat and air required for a full-scale dryer, given in the appendix.

II. DESIGN AND CONSTRUCTION OF PILOT-PLANT CONTINUOUS OVEN FOR DRYING AND CURING

Specifications

The experiments reported in Part I of this paper demonstrated that drying in 2 min., heating up in 1/2 min. and curing in 1 min. produced a satisfactory batt quickly enough to be commercially feasible. The next step was to utilize this information in the design of a continuous pilot-plant scale drying-curing oven.

After preliminary calculations, a length of 28 ft. was selected for the oven. To accommodate a schedule of drying in 2 min. and curing (including warmup) in 1 1/2 min., the oven was divided into a drying zone of 16 ft. and a curing zone of 12 ft. A conveyor speed of 8 ft./min. was established.

Since air velocity had effectively restrained products having densities of nominal 2 lb./cu.ft. during drying, a holddown conveyor was not provided; however, space was allowed to permit installation of such a device should it become necessary to dry products of greater density.

Commercial experience with dryers indicates that a holddown conveyor will probably be needed even for low densities because air pressure is difficult to control over the 7 to 8 ft. widths normally found in full-scale equipment.

To permit more uniform distribution of air in the pilot-plant oven, each zone was subdivided into 2 ft. long cells, each with its own diffuser and return line. To further improve the control of air within cells, hinged trapdoors were attached to the bottom of the partitions between cells.

Separate air-handling and heating systems were provided for the drying and curing sections. Finned tube surface area, sufficient to achieve a temperature of 225° F. (30 p.s.i.g. steam) at a peak flow rate of 250 c.f.m. per square foot of drying area, was installed in the drying-zone heating system. Similarly, finned tube surface area capable of achieving 325° F. (120 p.s.i.g. steam), at a peak airflow rate of 250 c.f.m. per square foot of curing area, was installed in the curing-zone heating system. To increase versatility, 12 electrical finned strip heaters, of 500 watts each, were installed in the plenum of the curing zone to permit air temperatures as high as 400° F. Makeup air in each of the air systems can be varied from 0 to 100 percent. Steam was selected because conditions in the pilot-plant area where the dryer was to be located prohibited use of an open-flame, gas-fired heat source.

To incorporate added flexibility in operation of the oven, provisions were made for varying the conveyor speed from 3 to 25 f.p.m., the speed of the air-system fan on the drying end of the oven from 900 to 2,050 r.p.m. (optimum 940 r.p.m.), the speed of the fan on the curing end from 835 to 1,600 r.p.m. (optimum 835 r.p.m.), and the temperature of the air from room temperature to 225° F. for drying, and to 325° F. for curing.

Figure 3 shows details of internal construction of the drying/curing oven.

For ease in installation, the unit was fabricated of 24-gauge galvanized iron in four 7 ft. long sections and then assembled on site. Figure 4 shows the dryer before the aluminumfaced, fiber glass insulation was applied. Figure 5 shows the fan and heater installations prior to installation of fiber glass insulation.

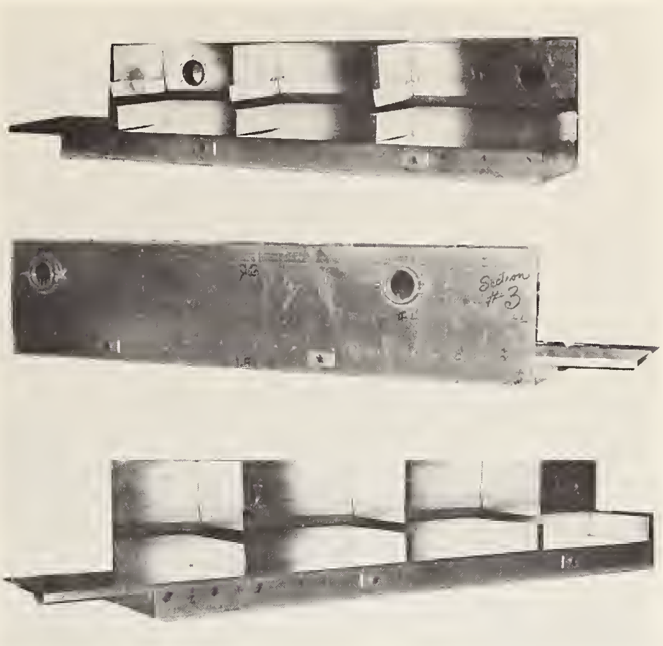

Figure 3.--Details of internal construction of pilot-scale dryer-curer for cotton batting.

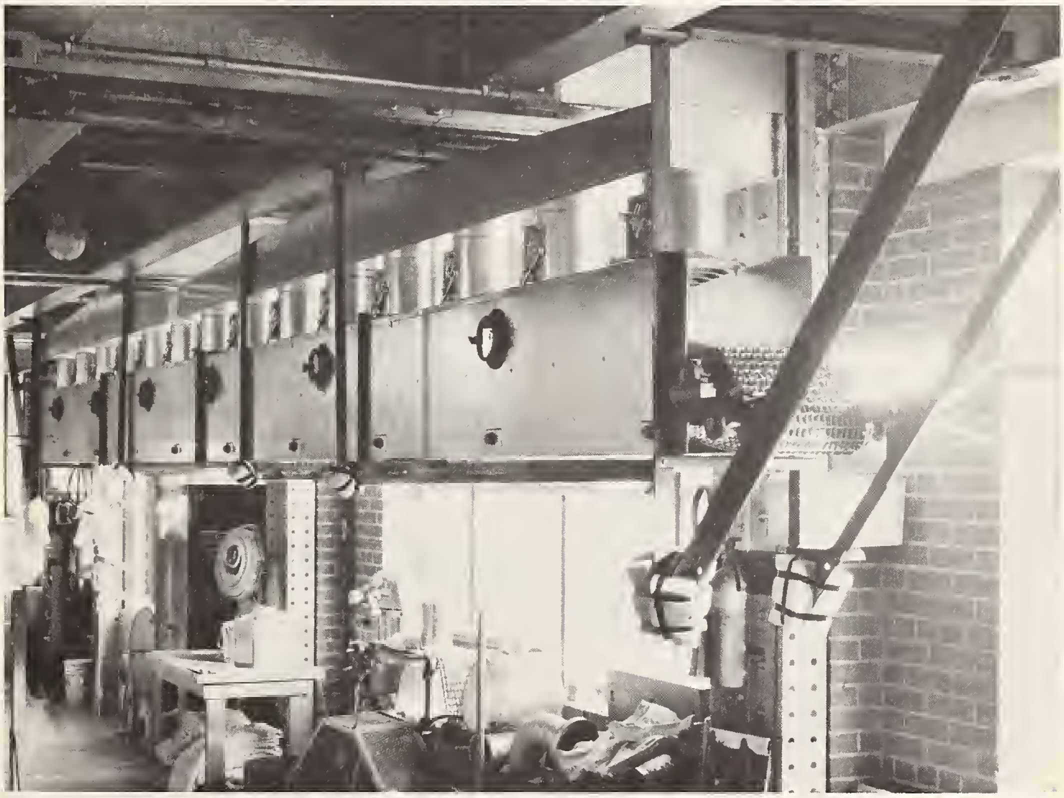

Figure 4.--Installed pilot-scale dryer-curer.

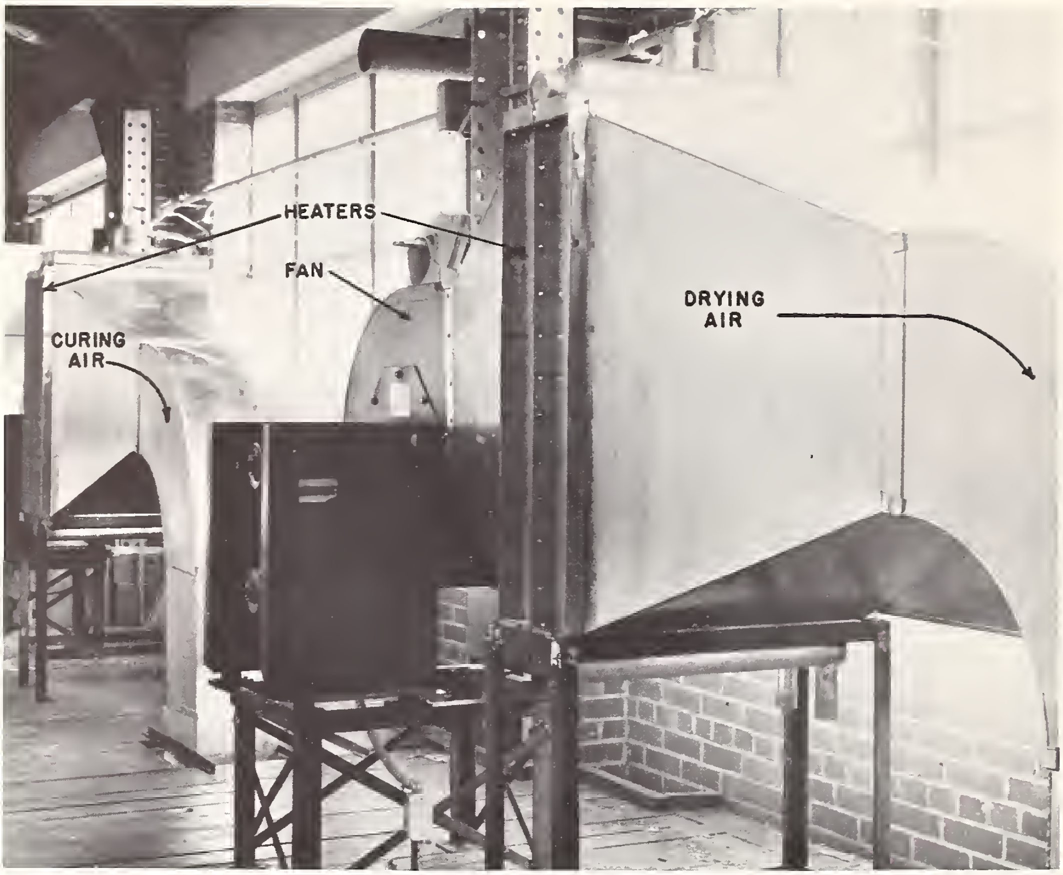

Figure 5.--Fan and heater installations for pilot-scale dryer-curer.

Preliminary Evaluation

The results of preliminary evaluation of the pilot-plant oven are shown in tables 5 and 6. The data in these tables show the effects of conveyor speed and of differential pressure on the expansion of the product during drying. With the oven, it was possible to produce, on a continuous basis of drying and curing, resin/latex-treated cotton batt products that compared satisfactorily with experimental products made in the cabinet-type dryer. The results confirmed that no holddown conveyor was needed under the conditions established for evaluation in the pilot-plant. These tests also indicated that the optimum pressure drop through the batting during drying was about 0.3 in. of water to achieve products having the desired density of 1.8 to 2.2 lb./cu.ft. Higher pressure drops across the in-process products resulted in cured batting that had a higher density.

CONCLUSIONS

Spray-damp cotton batting is sufficiently permeable to air to permit practical drying conditions to be achieved at acceptably low pressure drops.

TABLE 5.--Density of cotton batting product as a function of pressure drop through the sample and of the fan speed during drying in pilot-plant continuous oven. Curing zone differential pressure held constant at 0.2 inch of water and 315° F.

Differential pressure	Fan speed	Approx. air velocity through sample	Density range
Inch of water	R. p. m.	Ft./min.	Lbs./cu. ft.
0.3	930	100	1.96 - 2.30
0.5	1600	200	1.93 - 2.40
0.6	1800	210	2.25 - 2.70
0.7	2000	230	2.31 - 2.78
0.9	2050	240	2.47 - 3.34

TABLE 6. --Increase in thickness of cotton batting as a function of time of drying in pilot-plant continuous oven[1]

Oven length		Time in dryer		Differential pressure		Temperature		Average increase in thickness
Feet		Minutes		Inch of water		Degrees F.		
Dry	Cure	Dry	Cure	Drying	Curing	Drying	Curing	Percent
16	12	5 1/3	4	0.30	0.20	200	300	6.8
16	12	3 1/5	2 2/5	0.30	0.20	200	300	12.0
16	12	2	1 1/2	0.30	0.20	200	300	24.3
28	12	9 1/3	1 1/2	0.30	0.20	200	300	14.2
28	12	5 3/5	1 1/2	0.30	0.20	200	300	11.0
28	12	3 1/2	1 1/2	0.30	0.20	200	300	14.0
16	12	5 1/3	4	0.24	0.20	230	300	26.0
16	12	3 1/5	2 2/5	0.24	0.20	230	300	33.0
16	12	2	1 1/2	0.24	0.20	230	300	31.6
16	12	5 1/3	4	0.30	0.22	240	300	16.0
16	12	3 1/5	2 2/5	0.30	0.22	240	300	11.5
16	12	2	1 1/2	0.30	0.22	240	300	20.0

[1] Fan speeds for all runs:
930 r.p.m. for drying. Approximately 100 f.p.m./sq. ft. of product.
835 r.p.m. for during. Approximately 85 f.p.m./sq. ft. of product.

Each condition of drying, such as time, pressure drop through the material, and temperature of the drying air, affects the properties of the finished product. There are indications that humidity also affects the quality of the product. The tests required for determining the precise effects are beyond the scope of the equipment used and will be covered in a subsequent paper.

Under the conditions selected, the expansion that occurs during the drying or resin/latex spray-treated cotton batting can be controlled by the velocity of drying air without mechanical restraint. However, holddown conveyors will probably be required on commercial size dryers.

In summary, results from preliminary laboratory and pilot-plant work show that cotton batting that has been impregnated to a wet add-on of approximately 100 percent by weight of the original cotton with resins and latexes can be successfully dried and cured in a continuous process under conditions that are commercially acceptable.

The laboratory conditions for accomplishing this end were:

(a) Garnetting a blend of fibers consisting of 60 percent first-cut linters and 40 percent textile wastes of various grades.

(b) Spraying the web with a solution/suspension containing resins and latexes in approximately equal proportions.

(c) Controlling the concentration of the spray solution to about 20 percent solids.

(d) Maintaining a wet add-on of approximately 100 percent by weight of the cotton fed.

(e) Lapping the spray-damp webs into an array usually 20 webs thick which after drying and curing forms a product of nominal 1 in. thickness having a density within the range of 1.8 to 2.2 lb./cu.ft.

(f) Passing 200° F. air of 5 percent relative humidity at the rate of 80-100 f.p.m. for 2 min. through the spray-damp batting to accomplish drying, and 300° F. air through the dried batting at a minimum rate of 45 f.p.m. to accomplish heat-up to 300° F. in 1/2 min., and curing in an additional 1.0 min.

The experimental pilot-plant scale drying and curing oven developed in this research is satisfactory for the purpose intended.

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APPENDIX

Sample Calculations for Heat and Air Requirements for the Drying and Curing of Cotton Batting Treated by the Wet Process System

For this sample calculation, the following operating conditions were selected:

(1) The air for drying and curing is unidirectional, that is, it will flow through the batting being dried from top to bottom, and 100 percent makeup air is used.

(2) The wet add-on is 100 percent by weight of the cotton fed.

(3) The solids content of the treating solution is 20 percent.

(4) The product density is 2.0 lb./cu.ft.

(5) The product thickness is 1.0 in.

(6) The drying temperature is 200° F. The curing temperature is 320° F.

(7) The minimum drying time is 2 1/2 min. The minimum heat-up time from 200° F. to 320° F. is 1/2 min. The minimum curing time is 1 min. at 320° F.

(8) The average dry bulb temperature of the entering air is 70° F.

(9) The relative humidity of the entering air is 65 percent, and its absolute humidity is 0.0100 lb. of water per pound of bone dry air.

(10) The average dry bulb temperature[4/] of air in the dryer discharge stack is 165° F.

(11) The average wet bulb temperature of air in the dryer discharge is 109° F., and its absolute humidity is 0.0435 lb. of water per pound of bone dry air, or a relative humidity of about 18 percent.

(12) The average temperature of the spray-damp batting entering the oven is 70° F.

(13) The differential pressure across the batt during drying is within the range of 0.5 in. water.

(14) The differential pressure across the batt does not exceed 0.5 inch of water during the curing process.

(15) The equilibrium moisture content of the cotton rawstock is 7.0 percent at 70° F.

(16) The equilibrium moisture content of the cotton is 2.0 percent at 200° F. Assumed completely removed at 250° F.

(17) The product and the dryer are both 8 ft. wide. The following constants are used in these calculations: At 70° F. and standard barometric pressure, the density of dry air is 0.075 lb./cu.ft., and its specific volume is 13.34 cu.ft./lb.

Air at 165° F. and 18 percent relative humidity has an absolute humidity of 0.0453 lb. of water per pound of bone dry air, a density of 0.059 lb./cu.ft., and a specific volume of 16.9 cu.ft./lb.

The latent heat of vaporization of water at 250° is 945.5 B.t.u./lb.

The specific heat of water is 1.0 B.t.u./lb./° F.

The specific heat of the cotton is 0.3 B.t.u./lb./ F.

The specific heat of the resins is 0.3 B.t.u./lb./ F.

The humid heat of moist air is $0.237 + 0.45H$ B.t.u./lb./ F., where H = the absolute humidity in pounds of water per pound of bone dry air.

Heat losses through insulation to surroundings and heat required to warm up the conveyor belt will not be estimated here. These losses will vary greatly, depending upon the design of the oven and the type and thickness of insulation used. The following equation can be used to estimate these losses:

$$q = \left(\frac{A}{R}\right)\left(\Delta T\right)$$

where

A = area insulated, in square feet;

$R = R_{\text{(air)}} + R_{\text{(metal)}} + R_{\text{(insulation)}}$;

and

$$R_{\text{(air)}} = \frac{1}{1.25}$$

$$R_{\text{(metal)}} = \frac{\text{metal thickness, in feet}}{\text{64 (if galvanized iron)}}$$

and

$$R_{\text{(insulation)}} = \frac{\text{thickness, in feet}}{\text{0.021 for fiber glass}}$$

also

ΔT = temperature differential between inside and outside ° F.

With 1 sq. ft. of product 1 in. thick as a basis, components are identified as follows:

Given a product density of 2.0 lb./cu.ft.,

then 1 sq. ft. weighs $\frac{2.0\text{ lb.}}{12\text{ in.}} = 0.1667$ lb./sq. ft. 1 in. thick

The wet add-on is assumed to be 100 percent.

[4/] In these calculations, an overall average exit air temperature of 165° F..is used. Figure 2 shows the temperature records of the upper and lower surfaces of the batting sample, and also the wet and dry bulb thermocouple readings for inlet and exit drying air. Where test conditions closely simulate proposed operating conditions, a better estimate of fan and heater requirements can be made from a more accurate estimate of the overall average temperature of exit air. One method (10) of accomplishing this is to plot the change in absolute humidity of exit air against drying time, integrate, and determine the overall average humidity of the underside air. With this value and the wet bulb temperature, which varies only slightly throughout the drying test, the dry bulb temperature (which is the overall average exit air temperature) can be determined from the psychrometric chart.

Since the spray solution contains 20 percent solids, this amount remains on the cotton after drying, and the net add-on can be calculated on a dry basis as follows:

$$\frac{0.20 \text{ lb. resin}}{1 \text{ lb. cotton} + 0.2 \text{ lb. resin}} \times 100 = 16.67 \text{ percent resin.}$$

Therefore, each square foot 1 in. thick contains 0.1667 X 0.1667 lb. of resin, or a total of 0.0278 lb. of resin. Consequently, the weight of 1 sq. ft. of cotton in treated cotton batting 1 in. thick is
0.1667 lb. - 0.0278 lb. = 0.1389 lb.
Since the wet add-on is 100 percent, 0.1389 lb. of treating solution is used; and since the treating solution contains 20 percent solids, the net weight of solids is
0.20 X 0.1389 lb. = 0.0278 lb. This is a check of the values calculated above

Therefore, with a wet add-on of 0.1389 lb., the water to be evaporated is:
0.1389 lb. - 0.0278 lb. of resin solids = 0.1111 lb. of water. The equilibrium moisture content of the cotton at 70° F. is assumed to be 7 percent; therefore, the cotton contains
0.1389 lb. X 0.07 = 0.0097 lb. of water. All of this is not evaporated because the equilibrium moisture content of the cotton at 200° F. is assumed to be 2 percent, consequently
0.1389 lb. X 0.02 = 0.0028 lb. of water remain after drying.

The total water removed is:
0.1111 + 0.0097-0.0028 =
0.1180 lb. of water.

The bone dry weight of the cotton is
0.1389 lb.-0.0097 lb. =
0.1292 lb. of cotton.

The total weight of water to be heated is
0.1111 lb. + 0.0097 lb. =
0.1208 lb. of water.

The heat in B.t.u. needed to raise the temperature of 1 sq. ft. of spray-damp cotton batting from 70° F. to 200° F. is:

Water: 0.1208 lb. X
1 B.t.u. X
(200° F. - 70° F.) = 15.70 B.t.u.
Cotton: 0.1292 lb. X
0.3 B.t.u. X
(200° F. - 70° F.) = 5.04 B.t.u.
Resins: 0.0278 lb. X 0.3 B.t.u. X
(200° F. - 70° F.) = 1.08 B.t.u.

Total heat requirements to raise batting to 200° F. = 21.82 B.t.u.

The heat in B.t.u. needed to evaporate the water at 200° F. is:

Water: 0.1180 lb. X 977.8 B.t.u. = 115.38 B.t.u.

Therefore, the total B.t.u.'s needed to raise the temperature to 200° F. and to evaporate the water at 200° F. are:

21.82 B.t.u. + 115.48 B.t.u. = 137.30 B.t.u./sq.ft. 1 in. thick 2.0 lb./cu. ft. density product.

The heat requirements for curing are:

To heat

Water: 0.0028 lb. X 1 B.t.u. X
(250° F. - 200° F.) = 0.14 B.t.u.

To evaporate

Water: 0.0028 lb. X
945.5 B.t.u. = 2.65 B.t.u.

To heat

Cotton: 0.1293 lb. X 0.3 B.t.u. X
(320° F. - 200° F.) = 4.65 B.t.u.

To heat

Resins: 0.0278 lb. X 0.3 B.t.u. X
(320° F. - 200° F.) = 1.00 B.t.u.

Total heat required to cure
the cotton batting = 8.44 B.t.u.

The grand total of sensible heat in British thermal units required for drying and curing 1 sq. ft. of 1 in. thick, 2.0 lb./cu.ft. density cotton batting treated with a 20 percent solids treating solution to a 100 percent wet add-on is:

21.82 B.t.u. + 115.38 B.t.u. + 8.44 B.t.u. = 145.64 B.t.u.

For a production rate of 3,000 sq. ft./hr. of an 8 ft. wide product:

3,000 sq. ft./hr. at 8 ft. wide = $\frac{3,000}{8}$ = 375 linear ft./hr.

375 linear ft./hr. = $\frac{375}{60}$ = 6.25 linear ft./min.

Allowing 2.5 min. for drying, then:

2.5 X 6.25 = 15.625 ft. minimum for the length of the dryer section.

Allowing a heat-up from 200° F. to 320° F. of 0.5 min., then:

0.5 X 6.25 - 3.125 ft. minimum length for heat-up.

Allowing a curing time of 1 min., then:

1 X 6.25 = 6.25 ft. minimum curing section.

Total length for drying, heat-up, and curing sections is:

15.625 ft. + 3.125 ft. + 6.25 ft. = 25.00 ft. MINIMUM

The total heat in B.t.u./hr. required during drying must be furnished by the drying air; therefore:

3,000 sq. ft./hr. X 137.32 B.t.u./sq.ft. = 411,960 B.t.u./hr.

The heat given up per pound of air during its passage through the spray-damp batting is then calculated from the following formula:

$$Q_D = \Delta T \times S$$

where ΔT = the incoming dry bulb temperature - the exit dry bulb temperature °F.

$$S = 0.237 + 0.45 \text{ (lb. of water per lb. of bone dry air)} = \text{B.t.u./lb.}$$

$$Q_D = (200° \text{ F.} - 165° \text{ F.}) \times (0.237 + 0.45\ [0.010])$$

$$Q_D = 8.45 \text{ B.t.u./lb. of air}$$

Therefore the total air needed for drying is:

$$\frac{411{,}960 \text{ B.t.u./hr.}}{8.5 \text{ B.t.u./lb}} = 48{,}466 \text{ lb. of air per hour,}$$

or expressed in cubic feet per hour:

48,466 lb./hr. X 13.34 cu.ft./lb. = 646,536 cu.ft./hr. or in cubic feet per minute:

$$\frac{646{,}536 \text{ cu.ft./hr.}}{60 \text{ min.}} = 10{,}776 \text{ cu.ft. of air/min.}$$

The area within the drying section is:

A = 8 ft. wide X 15.625 ft. long = 125.0 sq. ft.

Then the velocity (air) to be supplied per square foot of product is:

$$V = \frac{10{,}776 \text{ cu.ft./min.}}{125 \text{ sq. ft.}} = 86.2 \text{ ft./min per sq. ft. of product.}$$

This value checks well with experimental data, which show velocity values between 60 and 130 ft./min./sq. ft. of product 1 in. thick and about 2.0 lbs./cu.ft. In this flow range, the pressure drop through the product is within the range of 0.17 to 0.55 in. of water, and drying times are within 2 to 8 min.

The heat requirements to raise the temperature from the average of 200° F. at the end of the drying to the 320° F. required for curing, and to evaporate the remaining water in the product must be supplied by the air in the heat-up and curing section of the oven. Therefore,

3,000 sq.ft./hr. X 8.44 B.t.u./sq.ft. = 25,320 B.t.u./hr.

The heat given up per pound of air in its passage through the batting is then calculated from the following formula:

$$Q_C = \Delta T \times S$$

$$Q_C = 320° \text{ F.} \ \frac{(320° \text{ F.} + 200° \text{ F.})}{2} \times (0.237 + 0.45[0.010])$$

$$Q_C = 14.49 \text{ B.t.u./lb. of air.}$$

Therefore the total air needed for curing will be:

$$\frac{25{,}320 \text{ BTU/hr.}}{14.49 \text{ BTU/lb.}} = 1{,}747 \text{ lbs. of air/hr.}$$

or expressed in volumetric flow rates:

1,747 lbs./hr. X 13.34 cu.ft./lb. = 23,305 cu.ft./hr.

or $\frac{23,305 \text{ cu. ft./hr.}}{60 \text{ min.}} = 388 \text{ cu. ft./min.}$

The area of the curing section including heat-up is:

A = 8 ft. wide X (3.125 ft. + 6.25 ft.) length

A = 75.0 sq. ft.

Then the velocity (air) to be supplied per square foot of product is:

$$V = \frac{388 \text{ c.f.m.}}{75.0 \text{ sq. ft.}} = 5.17 \text{ ft./min.}$$

Although computation of the absolute heat requirements indicates that an air velocity of 5.17 ft./min. would be enough to cure the product, this value is so low that adequate pressure drop through the product would not be obtained. To assure through circulation of the curing air, a minimum pressure differential of 0.2 in. of water across the product is needed. In general, experimental data from the pilot-scale oven show that a pressure differential of this magnitude corresponds to velocities of 30 to 50 cu. ft. of air per minute per square foot of 1 in. thick, 2.0 lb./cu. ft. product.

NOTE: Since particular operating conditions were selected as a basis for these calculations, they should be used only to estimate the approximate dryer size. Similar estimates for other throughputs of product can be made using these calculations. However, the ultimate lengths of oven chosen for other production rates may not vary in strict direct proportion because the degree that other factors, not included herein, may influence the design. These include uniformity of air velocity or air pressure on the surface during drying, humidity of drying air under sustained through-circulation operation, expected uniformity of spraying and garnetting that will be used, type and thickness of insulation, etc.